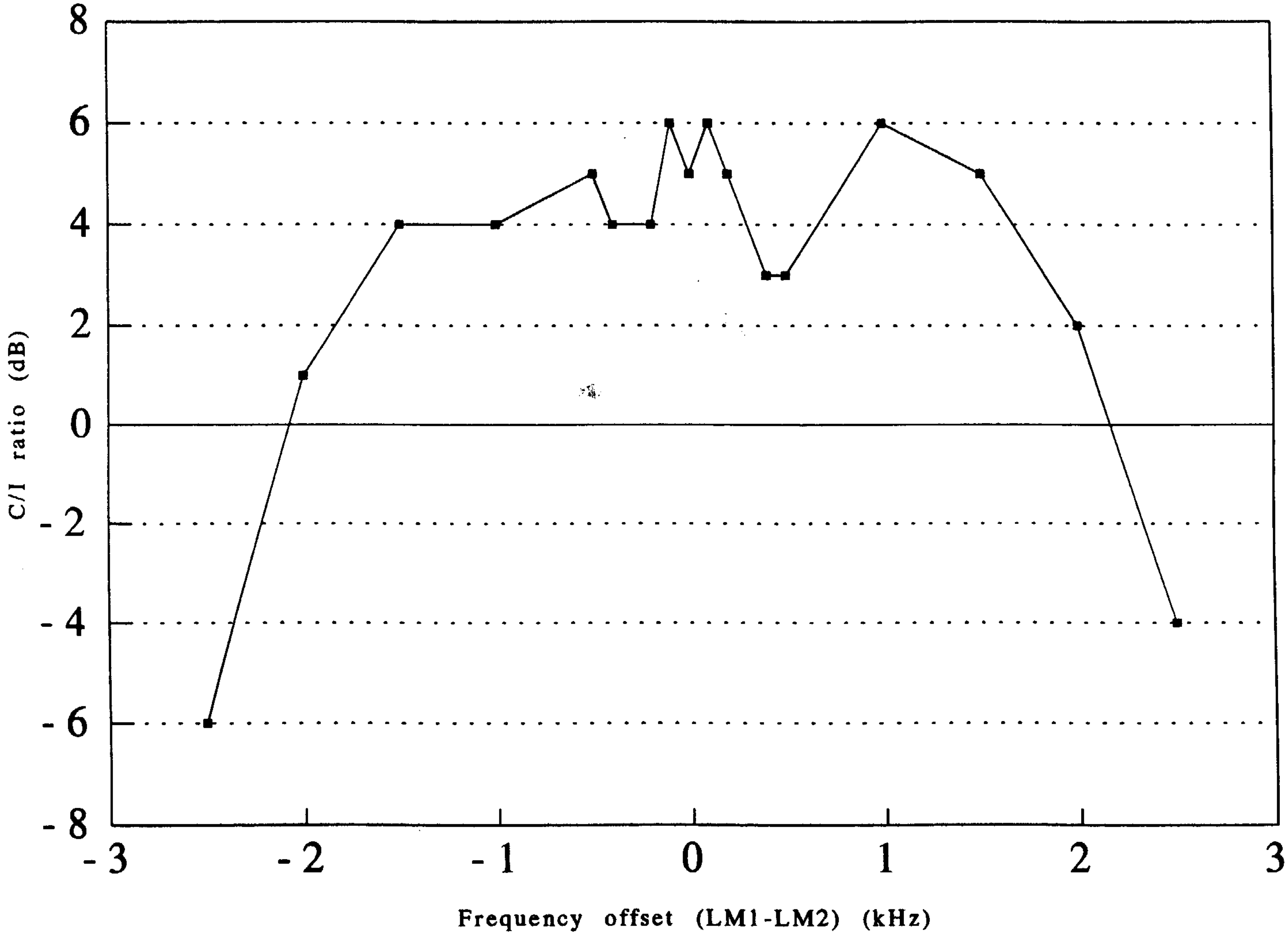
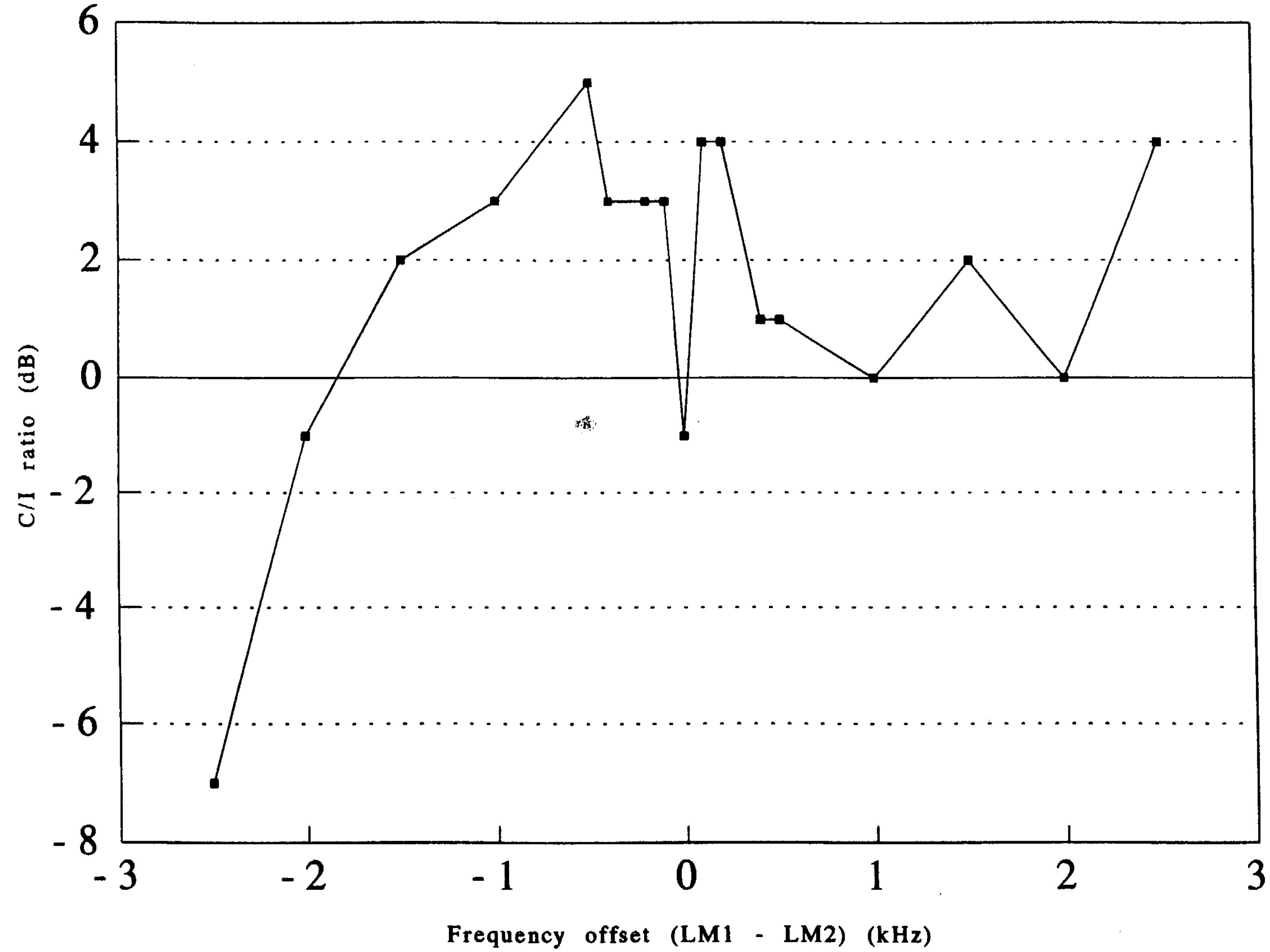
LM/LM Compatibility based on a degradation to a BER of 10^-2



Wanted Signal Level : MUS : -117dBm

Appendix 4
Figure 7

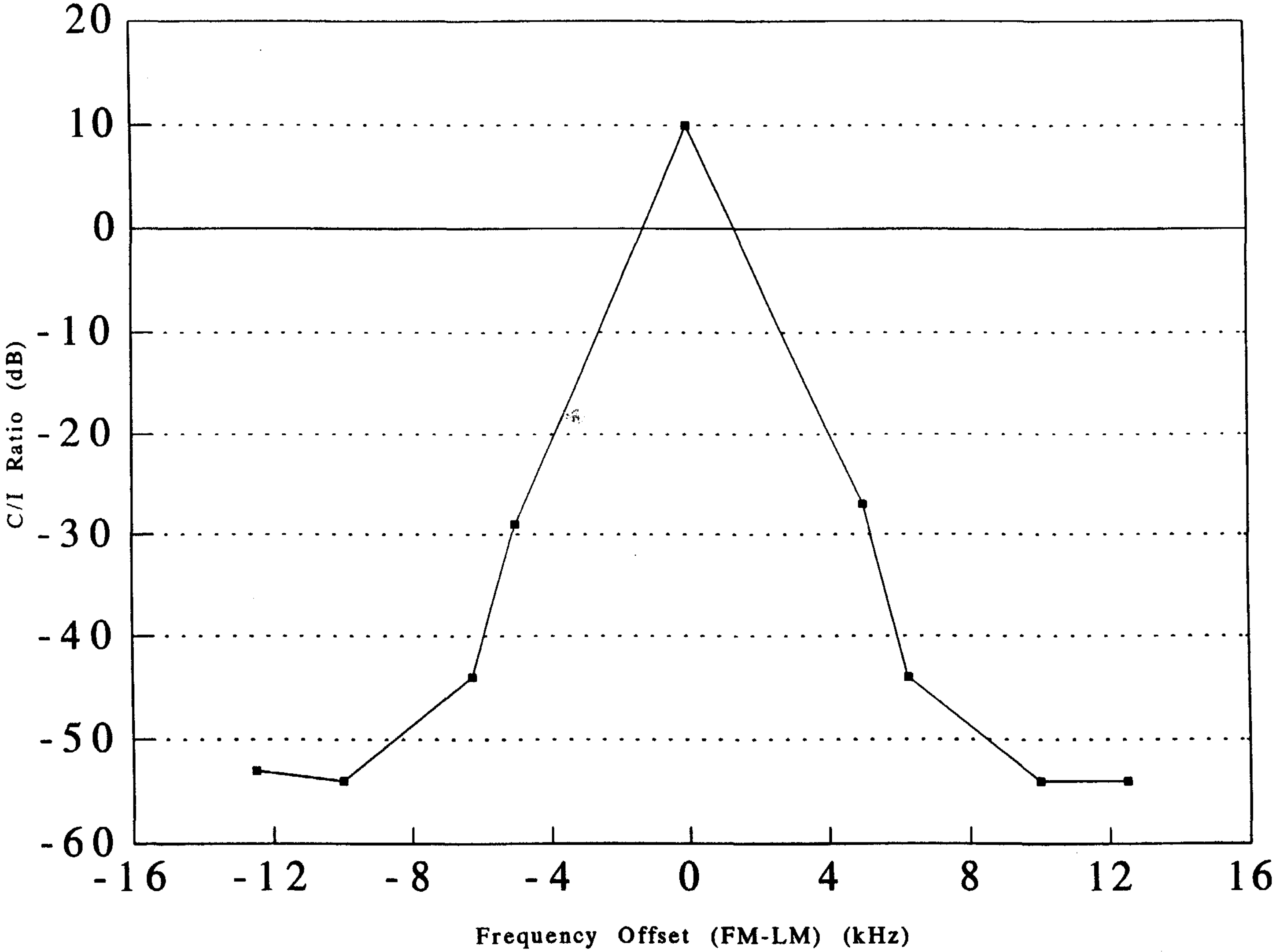
LM / LM compatibilty based on a degradation to a BER of 10^-2



Wanted Signal Level : MUS+15dB : -102dBm

Appendix 4
Figure 8

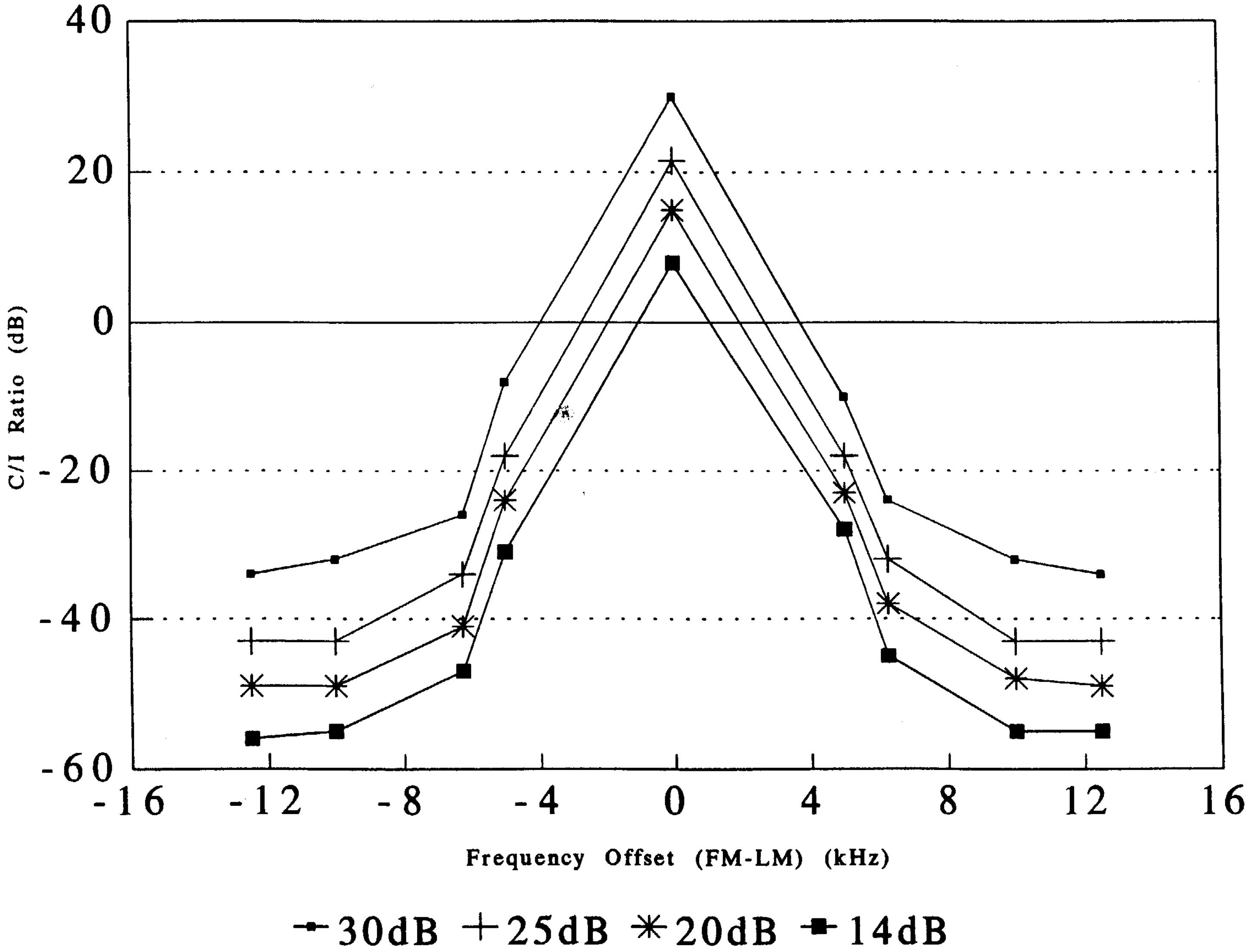
FM/LM compatibility based on a degradation to 14dB SINAD



Wanted Signal Level : MUS : - 107dBm

Appendix 4
Figure 9

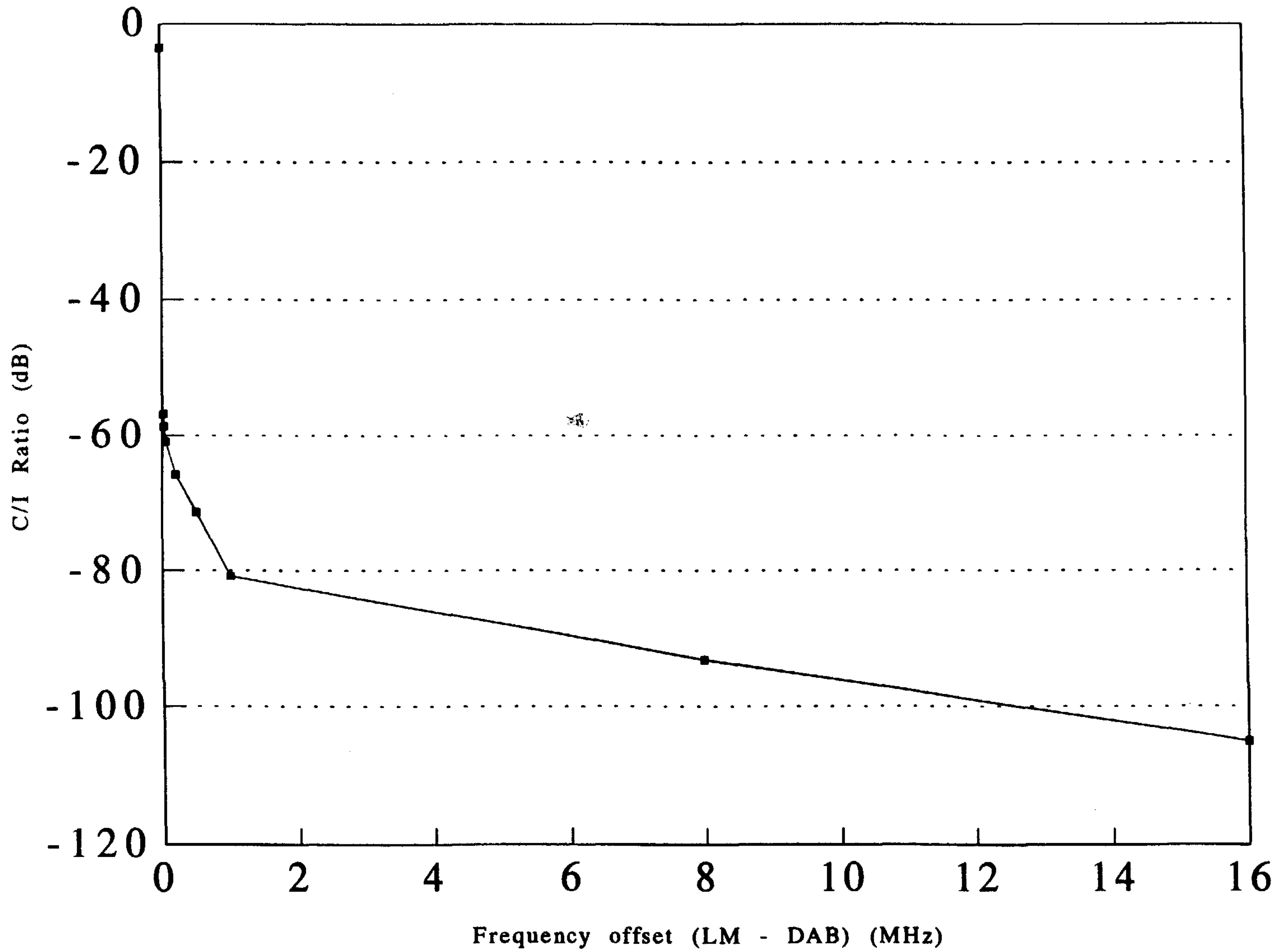
FM/LM co-channel compatibility



Wanted Signal Level : MUS+15dB : -92dBm

Appendix 4
Figure 10

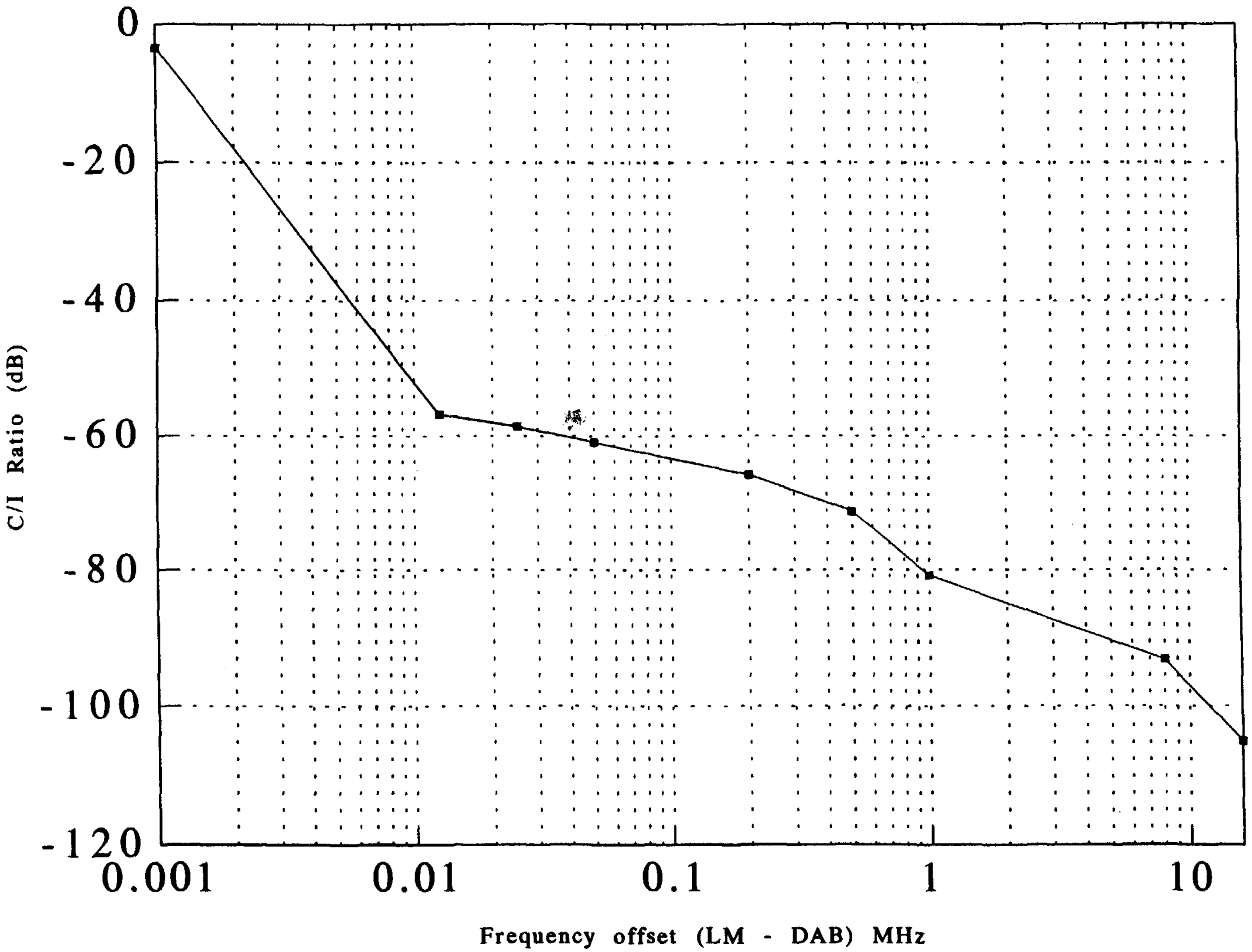
DAB/LM compatability based on a degradation to 14dB SINAD



Wanted Signal Level : MUS : -100dB

Appendix 4
Figure 11

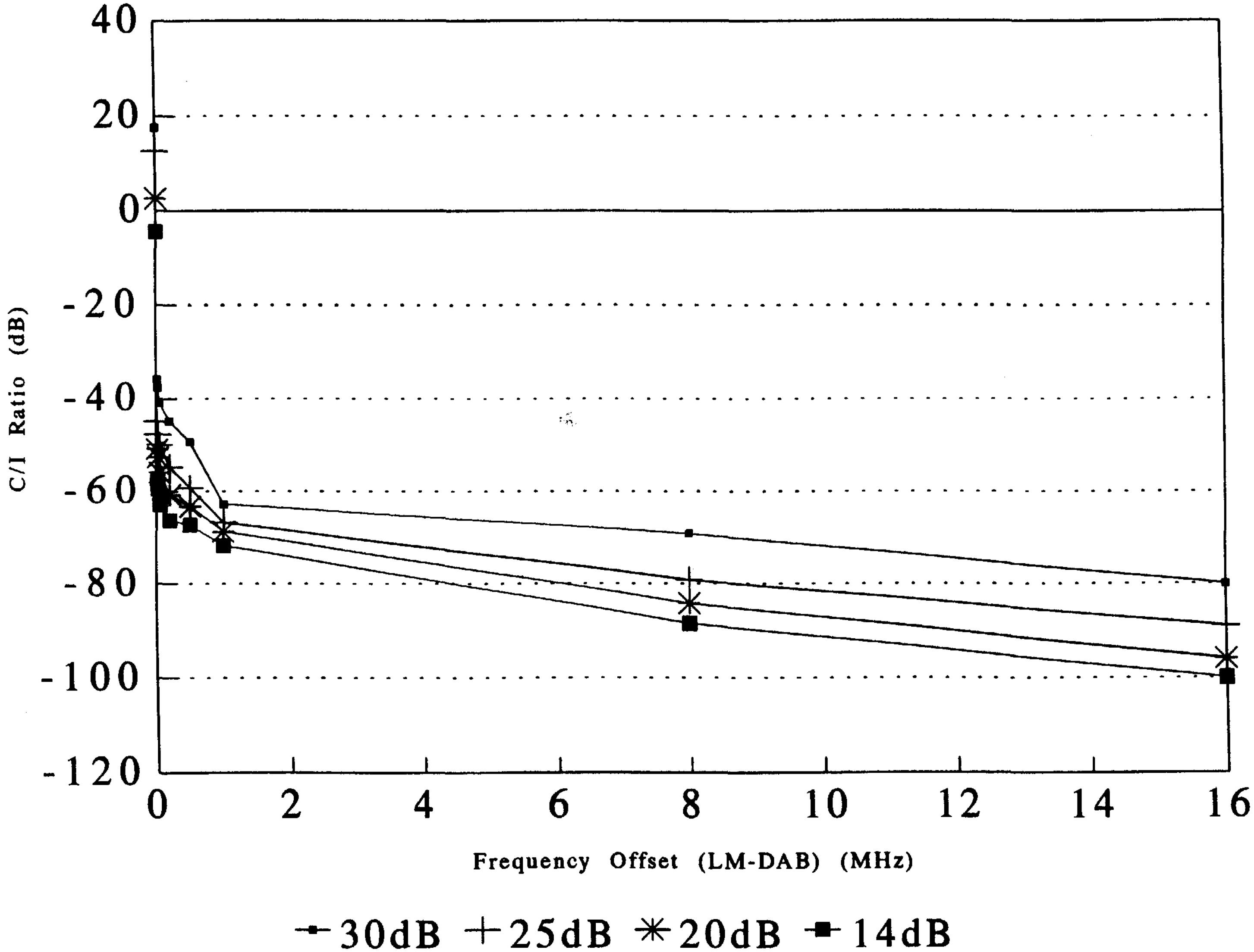
DAB/LM compatibility based on a degradation to 14dB SINAD



Wanted Signal Level : MUS : -100dB

Appendix 4
Figure 12

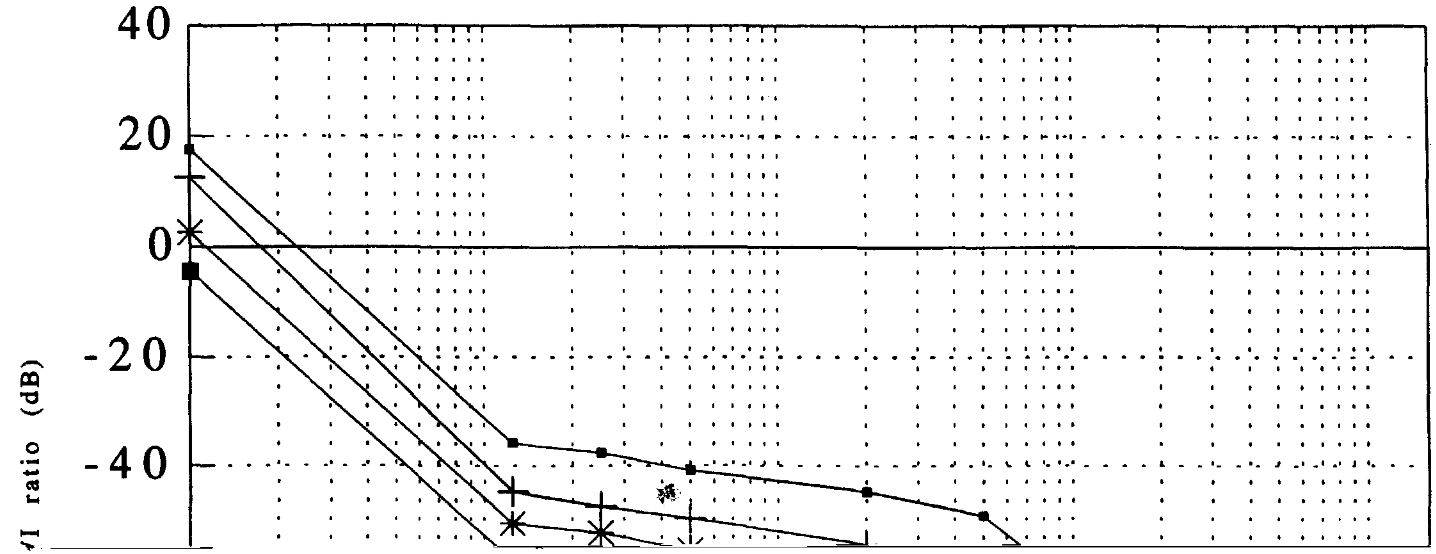
DAB/LM Co-channel Compatibility



Wanted Signal Level : MUS+15dB : -85dBm

Appendix 4
Figure 13

DAB/LM Co-Channel Compatibility



APPENDIX 5.

DAB CONVERSION FACTORS.

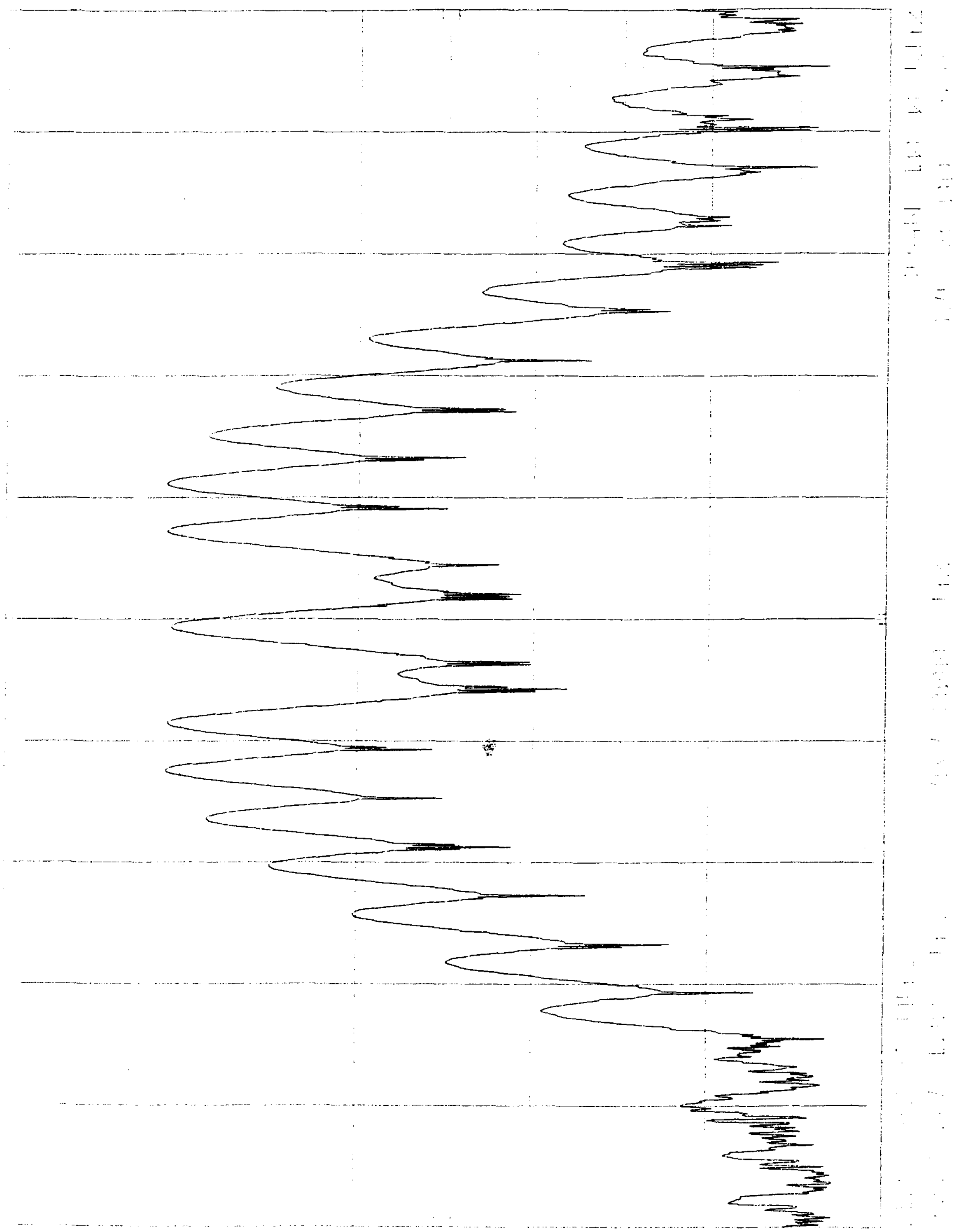
The DAB signal simulation is a wide band signal with a occupied bandwidth of 1500 MHz. To convert the signal levels measured on the HP8566B spectrum analyser to the appropriate signal level for protection ratio calculation, two correction factors were employed.

Co-channel Conversion Factor.

For a co-channel DAB signal the level of the unwanted is defined as that present in the 5 kHz bandwidth of the LM receiver.

Spectrum analyzer resolution bandwidth : 1 kHz.
Conversion factor to 5 kHz bandwidth : 10 log (required signal BW / measured BW).
: 10 log (5/1)
: 6.99 dB

Non Co-channel Conversion Factor.



Appendix 4

REPORT ON THE RELATIVE PERFORMANCE OF LINEAR MODULATION (TTIB-SSB) COMPARED TO FM AND AM MODULATION, WITH PARTICULAR REFERENCE TO INTERFERENCE PERFORMANCE

FINAL REPORT

C.C.E.BADEN and A.P.JENKINS

AUGUST 1990

FOREWORD

Over the years, the use of mobile radio has become more and more widespread, resulting in increased pressure on the spectrum allocated for use by mobile services. The transition from 25 kHz to 12.5 kHz channel spacing provided a significant increase in the number of available channels and the introduction of trunked radio systems has enabled the available channels to be used by a greater number of users. However, even with these improvements, the pressure on the spectrum still remains and methods for accommodating a larger number of users in a given bandwidth are still required.

It had been suggested that single sideband (SSB) transmissions could be used for mobile radio in 5 kHz channels using a transparent tone in band. These trials funded by the Radiocommunications Agency and conducted by Bradford University with Securicor Communications, investigated the transmission of both voice and data in a 5 kHz channel using SSB with Transparent Tone in Band (TTIB), a technique developed by Bristol University. The experiments were conducted over a variety of previously characterised propagation paths and vehicle routes and speeds in order to give results in various combinations of deep or shallow fades, strong or weak signal strengths and different fading rates.

The performance of the system was assessed by subjective testing, in the case of the voice tests, and by bit error ratio measurement for data transmissions. In each case, the performance of SSB was compared with the performance of 12.5 kHz AM and FM systems over the same paths.

As stated, SSB TTIB is one possible option which could increase the capacity available for mobile radio users from the radio spectrum. The results of the trials in this report and work undertaken elsewhere, have provided valuable information in assessing the merits and disadvantages of SSB TTIB for this purpose.

To date they indicate that there may be some benefit, in terms of spectral efficiency, to be gained by the introduction of this technique. Some interest in operating a SSB TTIB system has already been shown and the Radiocommunications Agency has been approached to consider licensing these systems. It is also likely that in the future more mobile radio equipment manufacturers and operators will wish to start operating SSB TTIB. Therefore both a licensing and type approval framework will be required to regulate the operation. To this end, the

Radiocommunications Agency has begun work on a type approval specification which will be appropriate for this equipment and intends to undertake further experimental work to determine appropriate protection parameters for channel planning.

Radiocommunications Agency
December 1991

ABSTRACT

This report details the series of field trials carried out between December 1989 and June 1990 to assess the performance of LM-SSB (TTIB) compared with FM and AM, in a trunked Private Mobile Radio (PMR) environment.

Mobile trials were carried out under a variety of defined conditions, with particular reference to the relative performance of these systems under adjacent and co-channel interfering conditions. Both data and voice quality were evaluated. Bit Error Rate measurements were obtained for data rates between 1.2 and 9.6kb/s and the Diagnostic Rhyme Test was used to assess voice intelligibility.

Comparative results are presented and the advantages and problems associated with integrating an LM-SSB system into the PMR environment are discussed.

ACKNOWLEDGEMENTS

The authors would like to thank the following people for their help during the course of this project:

R.A.HILLUM SECURICOR COMMUNICATIONS LTD.

[illegible]

CONTENTS

1. Introduction

With the ever increasing use of Private Mobile Radio (PMR) and cellular systems, spectrum congestion is becoming a more pressing problem. Hence the use of narrow band techniques to increase spectrum efficiency has become more desirable. The introduction of 5kHz SSB systems would therefore seem a natural progression towards effective spectrum utilisation. However, very little quantitative investigation has been carried out on assessing the effects of introducing "new technology" SSB into a trunked PMR working environment.[1,2,3,4]

In order to remedy this situation, the DTI (Radio Communications Agency) commissioned a series of field trials to assess the quality and integrability of SSB systems into the existing PMR infrastructure. The two parties involved in the project were Bradford University and Securicor Communications Ltd.

At the time, Securicor were already involved in the development of a particular variant of SSB modulation originated by Professor McGeehan at Bristol University (discussed in more detail in the following section), known as Linear Modulation SSB (LM-SSB). Coupled with Securicor's existing frequency allocation and availability of proprietary FM and AM equipment, the possibility existed for an investigation of interactions between SSB and carrier based modulation schemes in a significantly more controlled manner than had been possible hitherto.

The scope of the trials was to compare baseline characteristics with those under adjacent and co-channel interfering conditions. Experiments involving both voice and data were to be undertaken.

A full series of laboratory tests were also carried out on the equipment. These tests were based on a draft version of MPT1376, the document intended to cover type testing for PMR SSB equipment.

The SSB and FM equipment were trunked systems, using the MPT1327 trunking standard. The AM system was not trunked.

1.1 Background.

Both AM and FM[5] are fundamentally limited in their spectrum efficiency by requiring the occupied bandwidth of the radiated signal to be at least twice that of the baseband modulating signal. Additionally, an AM signal is degraded by amplitude fluctuations at a rate too fast for conventional AGC systems to be able to compensate and FM systems suffer from phase distortion.

Several alternative modulation schemes have, from time to time, been investigated. These include SSB suppressed carrier[6], SSB pilot carrier[7,8,9], Tone Above Band SSB (TAB SSB)[10,11], Tone In Band SSB (TIB SSB) and Transparent Tone In Band (TTIB SSB)[12,13,14,15,16] systems.

The equipment used in the trials utilised the TTIB technique in conjunction with a process known as Feed Forward Signal Regeneration (FFSR), in a system combination known as LM-SSB.

1.2 Linear Modulation Single Sideband.

The transmission of a pilot carrier or pilot tone is highly desirable for the purposes of AFC and AGC. However, there are several combinations of position for the pilot tone. In the TAB and pilot carrier systems the tone is placed above and below the audio passband respectively. This, however, renders the tone more vulnerable to adjacent channel interference and also requires asymmetric pull-in behaviour from the AFC circuitry. More significantly, the pilot tone for each of these two systems will be positioned in regions of high group delay with respect to the majority of the audio band. This is a result of group delay characteristics displayed by typical IF crystal filters (time delay spread of the received signal due to propagation effects at this frequency is known not to be a problem provided pilot to band edge spacing is less than 2kHz[17]).

The tone in band technique eliminates this problem by notching out part of the audio spectrum and inserting a pilot tone in its place. This system was found to be satisfactory for voice transmissions but its nontransparency to various data formats proved to be a problem.

The solution to the problem was put forward by J.P.McGeehan et al in the audio processing technique known as TTIB. Here, the audio spectrum is split into two halves and the complete higher frequency half is translated upwards in frequency by 400Hz (the figures here refer to the particular system under test – different values can be used for different circumstances). A 1850Hz pilot tone is then inserted into the resulting notch in the center of the audio spectrum and the composite signal is then transmitted using conventional SSB techniques. The resulting spectrum is illustrated in Fig 1.1 (courtesy Securicor Communications Ltd)

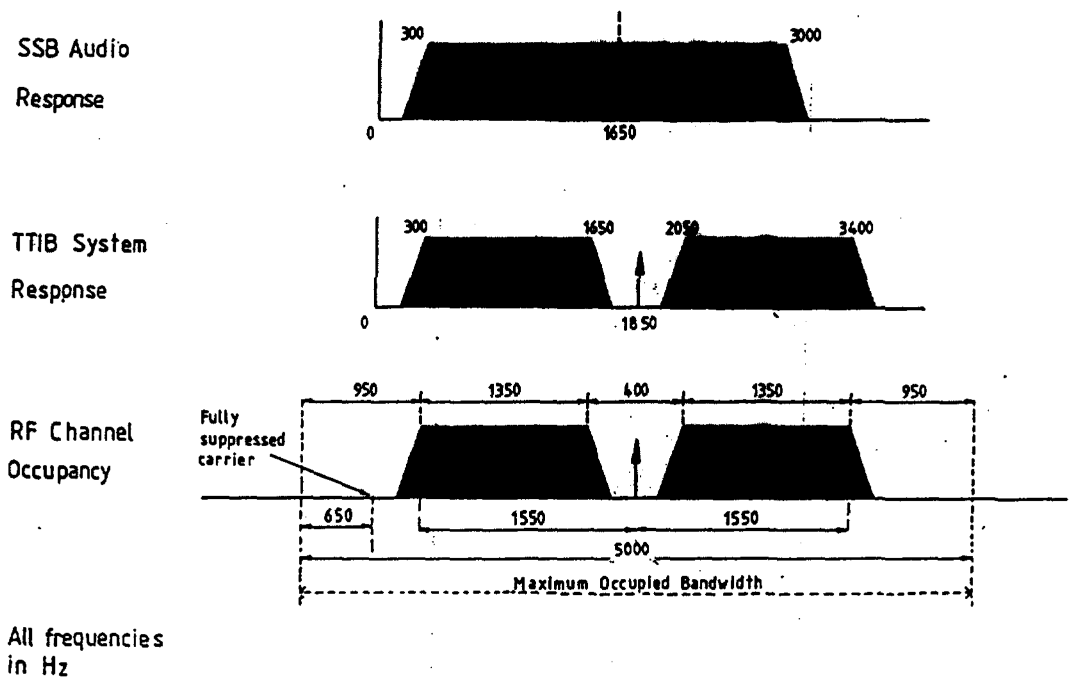


Fig 1.1 TTIB Spectrum

In the receiver, the final stages of the audio processing remove the pilot in the usual way for AGC and AFC purposes and perform a complementary downward frequency translation of the upper half of the audio spectrum, thereby regenerating the original 300Hz to 3kHz baseband signal. Thus, TTIB gives the user a complete 3kHz audio channel from the baseband transmitter input to the baseband receiver output, complemented with the advantages of the TIB system already discussed.

During the signal reconstruction, both amplitude and phase of all components across the passband are well preserved by phase locking the previously separate halves of the audio spectrum. As a result, the end-to-end transmission process is essentially linear and has become known as Linear Modulation (LM) SSB.

Finally, additional AFC and AGC functions are performed by a process known as Feed Forward Signal Regeneration (FFSR)[15]. The random amplitude and frequency fluctuations superimposed on the received signal as a result of multipath propagation can occur at rates of 36Hz (vehicle traveling at 70mph, f_c = 170MHz) and to a depth of around 35dB. These are removed by the FFSR processing in an audio "IF" stage before passing the signal to the TTIB processing. In the equipment used for the trials, all of the functions discussed were implemented using Digital Signal Processors (DSP's).

2. Equipment Performance Tests.

To be able to interpret and quantify the results of the trials that were carried out on the new Linearly Modulated, trunked SSB system being developed by Securicor Communications Ltd., a series of performance tests were required. (Appendix (i) shows the original Laboratory Test Schedule, which was amended as necessary.) This would enable an assessment of the effects that equipment quality has on adjacent and co-channel interference tests. Hence a clearer picture of the relative effectiveness of the different types of modulation techniques under various forms of interference can be deduced.

At present, only AM and FM systems are employed in the PMR environment and as a result there is no general test specification to cover trunked SSB systems. There is, however, a British Standard (BS6160)[18] which covers radio equipment used in mobile services; more specifically parts 4 and 5 which cover transmitters and receivers employing single-sideband techniques. This is in addition to a draft DTI specification (see Appendix ii) which, although not published or finalised yet, will form the backbone of the relevant MPT type testing specification for such SSB systems. As a result, the laboratory test schedule used was based extensively on this specification.

Note that, with the exception of the trunking board, the transmit and receive sections of the base station are identical to those used in the mobile. It was therefore unnecessary to test the base station performance as well.

Measurements were all taken under normal test conditions at Securicor Communications, Sutton during December 1989. A full list of test equipment used is given in Appendix (iii).

Two main problems were encountered during the testing of the equipment to the DTI specification. These were both concerned with the measurement of the Peak Envelope Power (PEP).

a) Sections 4.1 and 4.2 of the specification require the measurement of the frequency and power of the "reference carrier" respectively, in the absence of modulation. For the system under test, the pilot tone corresponding to the "reference carrier" is nominally −10dB with respect to the wanted signal and disappears in the absence of modulation. Therefore, for tests requiring the presence of the pilot tone without a modulating signal, a test mode was set up which produces a Full Power Pilot (FPP) tone at the usual frequency but with a power equal to the preset PEP of the unit.

b) The unit has both Automatic Level Control (ALC) and Automatic Gain Control